ENERGY ASPECTS
IN
COOLING TOWERS

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1.0 General

Cooling towers are extensively used in process, textile, chemical, power, electronic and other industries to cool the warm water arising from various operations. The cooling is accomplished by bringing warm water into contact with relatively unsaturated air. Cooling tower is an integral part of most of the utility equipments like air compressor, air conditioning machine etc., and plays a major role in improving the efficiency and specific energy consumption of these equipments. Even though cooling tower does not consume much energy by itself, its malfunction can cause a tremendous negative effect on the equipments that are using cooling water. Pumps and fans are the only energy consuming parts and generally consume 5–10% of the power consumed by utility equipments. Refrigeration units can take advantage of colder tower water to reduce power consumption. A refrigeration unit condenser can utilise inlet water temperatures down to 12.8^{o}C to reduce compressor energy consumption by 25 to 30 percent.

2.0 Cooling Tower Theory

Cooling tower operates on the principle of diffusional heat transfer. By bringing warm water into direct contact with cold air, water will be cooled by loss of sensible heat and by evaporation. The air in turn will be heated and humidified. The operation of water cooling represents, therefore, a case of simultaneous mass and heat transfer. This process involves :

1. Latent heat transfer owing to vapourisation of a small portion of water
2. Sensible heat transfer owing to the difference in temperature of water and air

Approximately 80% of this heat transfer is due to latent heat and 20% for sensible heat. The theory of cooling tower heat transfer process is based upon enthalpy potential difference. Each particle of water is assumed to be surrounded by a film of air and the enthalpy difference between the film and surrounding air provides the driving force for the cooling process. Exhibit 1 illustrates water and air relationship and the driving potential which exist in a counter flow tower, where air flows parallel but opposite in direction to water flow.

3.0 Cooling Tower Terminology

In order to carry out any specific calculations on cooling tower, it is necessary to have knowledge of the properties of air and water vapour mixtures over the relevant temperature. The relationship between most of these properties can be expressed in graphical form by a psychometric chart as shown in Exhibit 2 and are explained in Exhibit 3. Each cooling tower is designed to have a particular approach and range.

The difference between cooling tower discharge water temperature and the wet bulb temperature of ambient air is known as approach.

Range of a cooling tower is defined as the change in temperature in the water from inlet to outlet.

Some of the calculations related to cooling tower are given in Exhibits 4 and 5.

4.0 Types of Cooling Towers

A cooling tower is, in principle, a special type of packed tower. The usual packing material is cypress wood and plastics which is the most economical tower-filling that withstands the combined action of wind and water. Basically all cooling towers are the same in providing increased contact surface between the air and water.

Cooling towers can be classified into mechanical draft and natural draft depending upon the way in which air is supplied to the tower. A schematic representation of different types of cooling towers is shown in Exhibit 6. Also a brief description of each type is given below:

4.1 Forced Draft Tower

In the Forced Draft tower, the fan is mounted at the base and air is forced in at the bottom and discharged at low velocity through the top. This arrangement has the advantage of locating the fan and drive outside the tower, where it is convenient for inspection, maintenance and repairs. Since the equipment is out of the hot humid top area of the tower, the fan is not subjected to corrosive conditions.

4.2 Induced Draft Tower

In the Induced Draft tower, air is induced into the tower either concurrent or cross current to the water flow. These towers are more satisfactory in operation, since they provide a more uniform air distribution and reduce the danger of air recirculation, thus giving on the average a higher performance. However, they show slightly higher drift losses and higher running costs than other types, as the fan is placed at the air outlet.

4.3 Natural Draft Tower

Natural draft towers operate in the same way as a furnace chimney. Air is heated in the tower by the hot water it contacts, so that its density is lowered . The difference between the density of air in the tower and outside it causes a natural flow of cold air in at the bottom and the rejection of less dense, warm air at the top.

4.4 Atmospheric Tower

In the atmospheric circulation type, the circulation of air through the tower is essentially across it in a horizontal direction rather than up through it in vertical direction. Wind velocities alone are depended on for moving the air through the tower. The water is distributed by allowing it to fall over baffles of various types. The principal difficulties in the operation of such a type tower are to secure complete distribution of water over the lower surfaces and to prevent losses of water by wind.

5.0 Energy Audit Approach

Energy audit of cooling tower is performed to assess the present level of approach and range against its designed values and also to locate the areas of energy wastage and suggest ways to improve the same. During energy audit, various parameters such as :

— Wet bulb temperature of air

— Dry bulb temperature of air

— Cooling water inlet temperature

— Cooling tower outlet temperature

— Exhaust air temperature

— Electrical readings of pump and fan motors

— Water flow rate

— Air flow rate

are measured using portable instruments. The instruments used and the corresponding parameters measured are listed below :-

Instruments Used	Parameter Measured
1. Sling Hygrometer	Wet bulb and dry bulb temperature of air
2. Temperature Indicator with thermocouple	Water temperature
3. Flow meter	Water flow rate
4. Anemometer	Air flow rate
5. Power Analyser	Pump and fan electrical parameters

6.0 Factors Influencing Cooling Tower Performance

6.1 Atmospheric Conditions

Cooling tower performance is greatly affected by atmospheric conditions, particularly by the wet bulb temperature of the inlet air. In a given locality, the wet bulb temperature changes throughout the year, reaching its peak value only very occasionally. It would, therefore, be uneconomical to operate the tower designed on the basis of the maximum wet bulb temperature. A compromise between peak and average conditions has to be adopted. While designing or selecting a cooling tower, it is suggested to use the so-called "5%" wet bulb temperature, which is defined as the wet bulb temperature not exceeded by more than 5% of the total number of hours during summer months. It is estimated from the study of local meteorological data.

6.2 Tower Height

Cooling tower height determines the time of contact between the water and air which is governed largely by the time required for the water to discharge from the nozzles and fall through the tower to the basin. The time of contact is therefore obtained in a given type of unit by varying the height of the tower. Should the time of contact be insufficient, no amount of increase in the ratio of air to water will produce the desired cooling. It is therefore necessary to maintain a certain minimum height of cooling tower. Following table gives the approximate relationship between tower height and approach.

Approach	Approach Temperature °C	Cooling range °C	Tower height m
Wide	8 to 11	13.9 to 19.4	4.6 to 6.1
Medium	4 to 8	13.9 to 19.4	7.6 to 9.1
Close	4.4	13.9 to 19.4	10.7 to 12.2

6.3 Liquid Loading Rate

The cooling performance of any tower containing a given depth of filling varies with water concentration. It has been found that for satisfactory performance, water flow rate must be high enough to ensure satisfactory wetting of the packing, but it should not exceed an upper limit at which cascading commences. The minimum liquid flow rate at which complete wetting of the packing is attained is termed the minimum wetting rate (MWR). The wetting rate is defined as the volumetric liquid flow rate per unit periphery of packing. It has been found that maximum contact and performance are obtained with a tower having a water concentration of 2 to 5 gal/(Min.ft^2 of ground area).

6.4 Air Velocity

Water cooling is an operation in which most of the resistance to transfer is situated in the gas phase. High air velocity thus required for efficient transfer. This in turn makes pressure drop a critical consideration. Air velocity in an operating cooling tower must obviously be lower than the velocity which will cause flooding. The lower the velocity , the lower the cost of power and the larger the tower. The higher the gas velocity, the larger the power cost and the smaller the tower. Economically, the most favourable gas velocity depends on a balance between the cost of power and the fixed charges on the equipment. The range of superficial air velocities is 6 to 8 ft./sec and maximum economical air velocity is 300–400 fpm.

6.5 Tower Packing

In the cooling tower, because of the requirement of a larger air volume and small allowable pressure drop, it is customary to use spaced wooden slats of triangular or rectangular cross section, leaving the tower substantially unobstructed. The void space is very large, usually greater than 90%, so that the gas pressure drop will be as low as possible. Air water interfacial area is highly influenced by the type of tower fill and their arrangement inside the tower.

6.6 Liquid Air Distribution

Liquid air distribution have a major effect on column performance. The requirement of good contact between liquid and gas is hardest to meet, especially in large towers. The effect of channeling is the chief reason for the poor performance of large towers. Amount of channeling may be minimised by providing redistributors. In most cooling towers the liquid is introduced by spraying the water upward at the top so that it travels up and down before striking the first row of fill. This provides effective contact between air and water inexpensively. Distribution should be in such a way that the drift losses should be less than 0.25% of total water circulated. Liquid to air ratio in cooling tower is generally maintained between 0.75 to 1.5.

6.7 Elevation or High Altitude

At high altitudes, atmospheric pressure will be lower than one atmosphere. At reduced atmospheric pressure,the saturation line is higher, which in turn increases the potential and reduces the required size of tower, if all other conditions are the same. This occurs because the partial pressure of the water is fixed whereas the total pressure has been decreased. The humidity of the saturated air at higher elevation is also greater.

7.0 Potential Areas for Energy Conservation

7.1 Selection of Cooling Tower

Selection of cooling towers influence the operating cost to a great extent. They have to be selected properly, depending upon the heat load, seasonal changes, location, etc. The salient points of different cooling towers are given below :

a. Natural draft cooling towers are primarily suitable for very large cooling water quantities. They are commonly used in places where humidity and air temperatures are usually low. Fan power is saved.

b. Forced draft towers are particularly subject to recirculation of the hot humid discharged air into the fan intake owing to the low discharge velocity, which materially reduces the tower effectiveness. Since the fan is out of the hot, humid area, the corrosion is less.

c. Induced draft tower with counter flow arrangement is more efficient since the coldest water contacts the coldest air, thus obtaining maximum enthalpy potential. The greater the cooling ranges, the more difficult the approaches.

d. A long narrow spray pond is more effective than a square one, so that decreasing pond width and increasing pond length will improve performance. Performance can also be increased by decreasing the amount of water sprayed per unit of pond area, increasing the height and fineness of spray drops and increasing nozzle height above the basin sides.

e. The recommended L/G ratio and superficial air velocity for cooling tower design is 1.25 and 7 ft./sec respectively.

f. While selecting a cooling tower, equal weightage has to be given to both capital cost and the annual total operating cost of the tower.

7.2 Variation of Fan Speed

Cooling tower fan horse power can be reduced substantially as the ambient wet-bulb temperature decreases if two-speed fan motors are used. Theoretically, operating at half speed will reduce air flow by 50 percent while decreasing horse power to one-eighth of full speed operation. However, actual half-speed operation will require about 17 percent of the horse power at full speed as a result of the inherent motor losses at lighter loads.

Exhibit 7 shows a typical plot of outlet water temperatures when a cooling tower is operated (i) in the fan-off position, (ii) with the fan at half-speed, and (iii) with the fan at full speed. Note that at decreasing wet bulb temperatures the water leaving the tower during half speed operation could meet design water temperature requirements of say 85°F. For example, for a 60°F wet bulb, 20°F range, a leaving water temperature slightly below 85°F is obtained with design water flow over the tower. If the fan had a 100 hp motor, 83 hp would be saved when operating it at half speed. In calculating savings, one should not overlook the advantage of having colder tower water available for the overall water circulating system.

7.3 Variable Pitch Fan

Recent developments in cooling tower fan energy management also include automatic variable pitch propeller type fans and inverter type devices to permit variable fan speeds. These schemes involve tracking the load at a constant leaving water temperature.

The variable pitch arrangement at constant motor speed changes the pitch of the blades through a pneumatic signal from the leaving water temperature. As the thermal load and/or the ambient wet bulb temperature decreases, the blade pitch reduces air flow and less fan energy is required.

Inverters make it possible to control a variable speed fan by changing the frequency modulation. Standard alternating current fan motors may be speed regulated between 0 and 50 Hz. In using inverters for this application, it is important to avoid frequencies that would result in fan critical speeds.

The air loading can be regulated by varying the pitch of the fan blades, which can usually be rotated at a plus or minus 3° position from the mean. In summer the blades will be in a $+3^{\circ}$ position and in winter at -3° position of the fan delivers about 80 percent of the $+3^{\circ}$ air quantity, but the power saving is 40 percent. If requested, the cooling tower fabricator will specify the temperature range assumed by the cooling tower water at 80 and 120 percent of its design loading when the design air quantity is at the guarantee wet bulb.

7.4 Loading on Fan and Pump Motors

It is necessary to assess the present level of performance or efficiency of above motors. Various electrical parameters such as KW, KVA, pf, Volts, Amps and frequency are measured using power analyzer. By knowing the % loading and power factor of motors, it is possible to estimate operating efficiency from motor characteristic curves. If the efficiency is low, the possibility of replacing it with a new one have to be looked into after calculating the pay back period.

7.5 Light Weight Fan Blades

Fan blades are made up of wood, aluminium, FRP, etc. to minimise corrosion problem as they are always exposed to humid and warm air. Old big cooling towers are generally operated with heavy and big wooden fans. As we know the fan power directly depends on the weight, angle and speed of blades. Replacing heavy wooden blades, with light weight and high strength plastics such as FRP will reduce the initial torque required and the power consumption.

7.6 Chilled Water Generation from Cooling Tower

With today's emphasis on energy management, cooling towers have not been overlooked. During periods below 50°F ambient wet bulb temperatures, cooling towers have the temperature capability to furnish chilled water directly to airconditioning systems. For existing refrigeration cooling-tower systems, piping can be installed to by-pass the chiller to allow tower effluent to flow directly to cooling coils. After heat has been removed from the air stream, water returns directly to the cooling tower. Water temperature leaving the cooling tower is controlled between 8.9 and 12.2°C, usually by cycling cooling tower fans. Depending upon the cleanliness of the cooling tower water, it may be necessary to install a side stream or full flow filter to minimise contamination of the normally closed chilled water circuit. Exhibit 8 shows the general arrangement of this system. Substantial savings can be realised during colder months by eliminating refrigeration–compressor energy.

Several other methods involving cooling towers have been used to reduce refrigeration energy consumption. These systems, as applied to centrifugal and absorption refrigeration machines, are known as thermocycle or

free cooling systems. Water leaving the cooling tower is available below 10°C, the thermo cycle system permits shutting down the compressor prime mover or reducing steam flow to an absorption unit. Exhibit 9 shows the arrangement for a centrifugal refrigeration unit.

7.7 Pumping Power

Another important factor in analysing cooling tower selections, especially in medium to large towers is the portion of pump horse power directly attributed to the cooling towers. A counter flow type of tower with spray nozzles will have a pumping head equal to static lift plus nozzle pressure loss. A cross flow type of tower with gravity flow enables a pumping head to an equal static lift. A reduction in tower height therefore reduces static lift, thus reducing pump horse power. Lengthy pipes and high pressure drops in cooling tower circuit should be avoided to reduce power consumption of pumps.

7.8 Integration of Cooling Towers

Generally there are many cooling towers of varying capacities installed in a manufacturing plant. These are designed for maximum heat load and wet bulb temperature, hence most of the time they will be operated in underloaded conditions. Sometimes heat load to cooling tower may be minimum at the process starting and ending, and maximum at the middle. Once this exact cyclic load is known, it is possible to distribute the heat loads to other towers which are located closely so that minimum number of cooling towers are operated with optimum heat load and efficiency. This may probably cut down one or more cooling towers, which are partially loaded. The possibility of using existing fountain as a spray pond cooling tower for small heat load may be looked into for energy conservation.

7.9 Effect of Cooling Water on Plant Equipments

The temperature of cooling water directly affect other process equipments such as compressors, A/c condensers, heat exchangers and distillation columns, etc. In compressors high cooling water temperature will reduce the interstage cooler effectiveness and the volumetric efficiency. Low cooling water temperature is desirable in a/c condensers. A refrigerant unit condenser can

utilize inlet water temperature down to 12.8°C to reduce compressor energy consumption by 25 to 30 percent. In power plant, it fixes the turbine or engine discharge pressure and the ultimate recovery of heat. In distillation and evaporation processes, the operating pressure is highly influenced by cooling water temperature. Case studies 2 and 3.

7.10 Control and Operation of Cooling Tower

Recent developments in cooling tower fan energy management include the automatic switching on and off of cooling tower fans with a time delay after measuring the cooling water outlet temperature. If cooling water temperature reaches the lower set limit it switches off, and starts automatically if the temperature rises to the upper limit. This operation is more economical in winter. It is a good practice to maintain a daily record of the wet and dry bulb temperatures taken twice a day. This should help the operating personnel to manipulate the operational parameters of the cooling tower for energy efficiency.

7.11 Multistage Cooling Tower (Staging)

Multistage cooling tower can produce cooling water temperature very close (2°C) to the wet bulb temperature, with increase in fixed and operating cost. During winter, chilled water generated by this can be used in

refrigeration or cold applications. A trade off between the operating cost of A/c compressors and the multistage towers, has to be arrived at, before going into the implementation.

7.12 Proper Maintenance

Maintenance of cooling tower plays a vital role in its performance and operating cost. Cooling tower provides a favourable atmosphere for algae, fungi and bacteria growth on its eliminator plates, grids, etc. Heavy microbial growth will distort the air and water flow pattern and its intimate contact. It also increases the overall pressure drops in the cooling tower. This problem can be minimised by dosing fungicides and algicides in cooling water. Hardness of water increases as

water is continuously evaporated from cooling tower. Increased hardness will lead to increased scaling in cooling tower and also in the process equipments such as condensers and heat exchangers which increases the dirt factor and hence higher resistances to heat transfer thereby reducing heat transfer efficiency. Proper blowdown cycle has to be maintained to keep hardness within the acceptable levels. Higher water pH increases microbial growth whereas lower pH increases corrosion. Side covers of cooling tower has to be maintained properly. Any holes or gaps in that will lead to air bypass (induced or forced air escapes out without intimately mixing with water) and reduced approach temperature.

Case Study 1

Use of Cooling Tower Instead of Once-Through River Water

Observations

A tyre company uses an ammonia chilling plant to get chilled water for its milling process. Heat is rejected from the condenser of the chiller plant by a once-through cooling system employing river water. Since the river water must be pumped some distance, savings can be achieved by installation of a cooling tower. Details of savings are given below:

Assumptions

Cooling Tower Pump Efficiency	=	80%
Cooling Tower Height	=	30 Feet
Pumping Head Loss	=	10%
Make Up Water	=	20%

Data

Condenser Water to Drain	=	672 gpm
Water Treatment Plant Pump	=	90 hp; 1500 gpm
Average Water from WTP	=	38×109 monthly; 1016 gal. per minute
River Water Pumps	=	2×25 hp
Tank Water Pumps	=	55 KW (1172 gpm)

Calculations

Energy required to pump water from

$$\text{River to Tank} = \frac{(\text{Volume of condenser Water}) \times (\text{Load Factor}) \times \text{Pump R}}{\text{Capacity of River Water Pump}}$$

$$\text{Load Factor} = \frac{1016}{1500} = 0.68$$

$$= \frac{(672) \times (0.68) \times (140 \times 0.746)}{1500}$$

$$= 32 \text{ KW}$$

Energy Required to Pump Return Water From Tower to condenser Inlet

Pressure assuming 30 ft. tower + 10% loss = 33 ft of water

3ft of water = 0.4339 psig

= 0.4339×33

= 14 psig

Liquid Horsepower Required = $\dfrac{(\text{gal/min})\ (\text{Pressure})}{(1430)}$

= $\dfrac{(672)\,(14)}{(1430)}$

= 6.57 hp

Pump Horsepower = $\dfrac{6.57 \times 0.746}{0.8}$

= 6.1 KW

Energy to supply 20% Make Up = $\dfrac{(\text{Water Volume}) \times (\text{Pump Rating})}{(\text{Capacity of Tank Pump})}$

= $\dfrac{(672 \times 0.2) \times (104) = 11.9 \text{ KW}}{(1173)}$

Energy to Run Tower = (6.1) + (11.9)

= 18 KW

Energy Savings=(Pumping from River) – (Tower Consumption)

= 32 – 18 = 14 KW

Energy Savings

= (KW) (Hours/Operation)

= (14) (6912)

= 96,768 kWh $\times$ 0.0036

= 348 GJ

Cost Savings = (GJ/Year) (Rs. /GJ)

= (348) (411.11)

= 143,216 Rs. /Year

Cost of Implementation

The cost of a natural draught cooling tower is estimated to be Rs. 420,000.

Simple Payback $= \dfrac{420,000}{143,216}$

$= 2.9$ Years

Energy Savings	=	348 GJ/Year
Cost Savings	=	Rs. 143,216/Yr
Cost of Implementation	=	Rs. 420,000
Simple Payback	=	2.9 Years

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Case Study 2

Energy Savings by Adopting Indirect Cooling

Observation

Graphite electric furnace and its parts are cooled by demineralised water which is cooled indirectly through a heat exchanger using ordinary cooling water supplied from a cooling tower. This cooling water rejects its heat in the cooling tower. This system is connected by a 40 HP DM water pump and 30 HP raw water pump for cooling water.

Recommendations

It is suggested to modify the system to a direct cooling type and to replace the raw water pump by the DM water pump and by-pass the heat exchangers. The cooling water should be replaced by the DM water in the cooling tower and the quality is to be monitored regularly depending upon the TDS required to be maintained. The PH of the DM water should be maintained around 7.5 to 8 by chemical dosing. The quantity of make up water generally will not exceed 1.7% of the water flow rate.

Energy Savings	=	4.5 Lakh kWh/annum
Cost of Savings	=	Rs. 6.8 Lakhs/annum
Cost of implementation	=	Marginal
Pay back period	=	Marginal

Case Study 3

Effect of Cooling Tower Water on Compressor

Findings

Cooling tower in a central compressor house of an engineering industry was totally out of order. Cooling water was circulated with little cooling and the cooling tower was fully covered with algae, scales and dirts.

Data

Cooling water inlet temperature	=	43
Cooling water outlet temperature	=	37
Ambient air wet bulb temperature	=	25
Cooling tower designed temp. approach	=	2–5 °C
No. of compressors running	=	4
FAD capacity of each compressor	=	550 cfm
No. of hrs running per year	=	4500 hrs
Cost of Electricity (DG Set)	=	Rs. 2.0/kWh

Recommendations

Proper maintenance of cooling tower with adequate dosage of fungicide and algae chemicals

Energy Savings	=	45,000 kWh/Year
Cost Savings	=	Rs. 90,000/year
Cost of implementation	=	Rs. 25,000
Simple payback period	=	0.3 Years

Case Study 4

Energy Savings by Cleaning Fouled Cooling Tower

General

Main purpose of cooling tower is to reduce the inlet warm water temperature close to the wet bulb temperature of ambient air. Practically achievable approach temperature is 2–5°C. Because of algae growth, scale and corrosion, intimate contact between air and water, is not achieved, resulting in higher approach temperature. High cooling water temperature will reduce the overall subcooling of liquid refrigerant and NRE.

Data

Cooling tower water outlet temperature	=	30°C
Cooling tower water inlet temperature	=	34°C
Ambient air dry bulb temperature	=	23°C
Ambient air wet bulb temperature	=	20°C
Practically achievable water temperature	=	25°C
Deviation in cooling water temperature	=	5°C

Findings

Poor maintenance of cooling tower, resulting algae growth and higher approach temperature

Calculations

No. of compressor running	=	2
Compressor capacity	=	110 T each
Refrigerant quantity	=	20,500 lbs/hr
Approach in condenser	=	5°C
NRE of liquid refrigerant at 35°C and 60 psig	=	67.54 Btu/lb
NRE of liquid refrigerant at 30°C and 60 psig	=	77.24 Btu/psig
Net increase in cooling	=	4.7 Btu/lb of refrigerant
	=	$4.7 \times 20,500 = 96,350$ Btu/hr
	=	96350/12,000= 8.0 Ton of refrigeration

Therefore power wasted per year =

= 8.0 x 1.0 KW/Ton x 22 hrs /day x 300 days

= 52,800 kWh/year

= Rs. 1,05,600/Year

Recommendations

It is suggested to clean cooling tower thoroughly along with cooling water lines, strainers and pumps.

Payback Period

Energy savings	=	52,800 kWh/year
Cost savings	=	Rs. 1,05,600/year
Cost of implementation	=	Rs. 25,000
Pay back period	=	0.25 years

Case Study 5

Using Gravity Flow for Cooling Towers

Industry : Chemical Industry

Equipment: Cooling Tower

Findings

Cooling water was circulated to distillation column overhead condensers located at 30 m above the ground level. The outlet warm water was collected in the under ground hot well and pumped back to cooling tower with a 20 HP pump.

Data

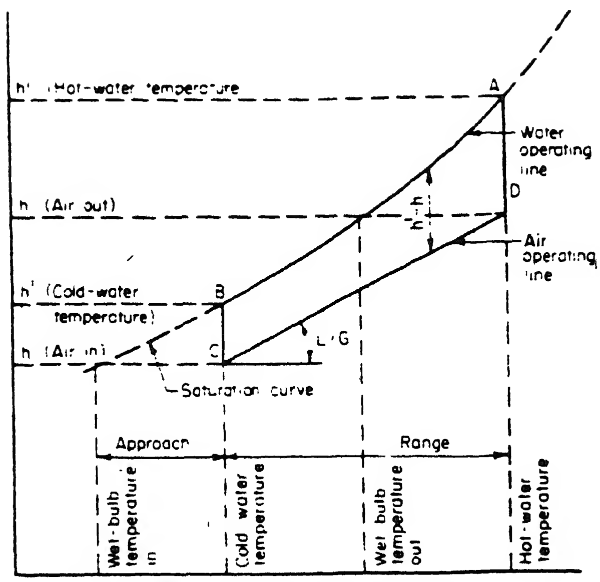
Power drawn by motor	=	11.2 KW
No. of hrs running/year	=	7200
Cost of electricity	=	Rs. 1.50/kWh

Recommendations

It is suggested to connect the condensers warm water directly to the cooling tower inlet, thus bypassing the hot well and pump. This will eliminate one 20 HP pump (75% loading) and save energy.

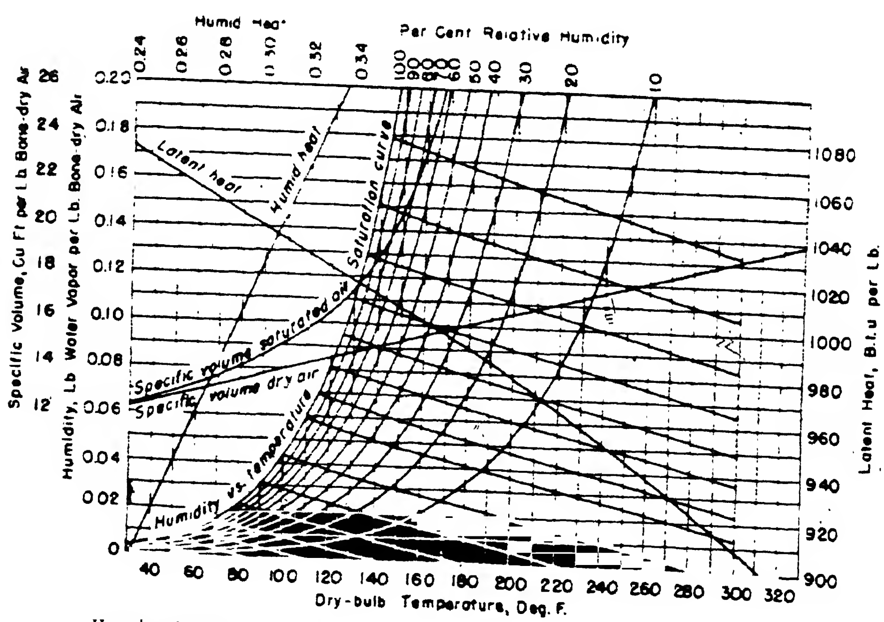
Energy savings	=	80,000 kWh/annum
Cost savings	=	Rs. 1,20,000
Cost of implementation	=	Marginal
Payback period	=	Immediate

EXHIBIT 1



Cooling-tower process heat balance. (Marley Co.)

EXHIBIT 2



Humidity chart for air-water vapor mixtures

Exhibit 3

Air Water Vapour Mixture – Terminology

1. Humidity

Is the mass of vapour carried by a unit mass of vapour free gas (Generally air)

2. Relative Humidity

Is defined as the ratio of the partial pressure of vapour to the vapour pressure of the liquid at the gas temperature. It is usually expressed on a % basis.

3. Percentage Humidity

Is the ratio of the actual humidity to the saturation humidity at the gas temperature also expressed on a percentage basis.

4. Humid heat

Is the Btu (Heat) necessary to increase the temperature of one pound or one gram of gas, plus whatever vapour it may contain by $1^{o}F$ or $1^{o}C$.

5. Humid volume

Is the total volume of a unit mass of vapour free gas plus whatever vapour it may contain, at 1 atm and the gas temperature.

6. Dew Point

Is the temperature to which a vapour gas mixture must be cooled (at constant humidity) to become saturated. The dew point of a saturated gas plant equals the gas temperature.

7. Total Enthalpy

Is the enthalpy of a unit mass of gas, plus whatever vapour it may contain.

Exhibit 4

Calculations

a) Tower Characteristic – (KVA/L)

The tower characteristics can be determined from the formula :-

$$\frac{K_aV}{L} = \int_{T_2}^{T^1} \frac{dT}{h^1 - h}\, dT$$

Where,

K = Mass transfer coefficient lb. water/h ft^2

Q = Contact area ft^2/ft^3 tower volume

V = Active cooling volume ft^3/ft^2 of plan area

L = Water rate lb/ h.ft^2

h^1 = Enthalpy of saturated air at water temp. Btu/lb

h = Enthalpy of air stream Btu/lb

T_1 & T_2 = Entering and leaving water temp (^oF)

Estimation of KaV/L by using quicker but less accurate method is given in Exhibit 5.

b) Fan Horse Power

$$\text{Horse power} = \frac{Q\,(hs)\,(d)}{33{,}000 \times 12}$$

Where Q	=	air volume ft^3/min
(hs)	=	static head, inches of water
d	=	density of water at ambient temp., lb/ft^3

c) Pump Horse Power

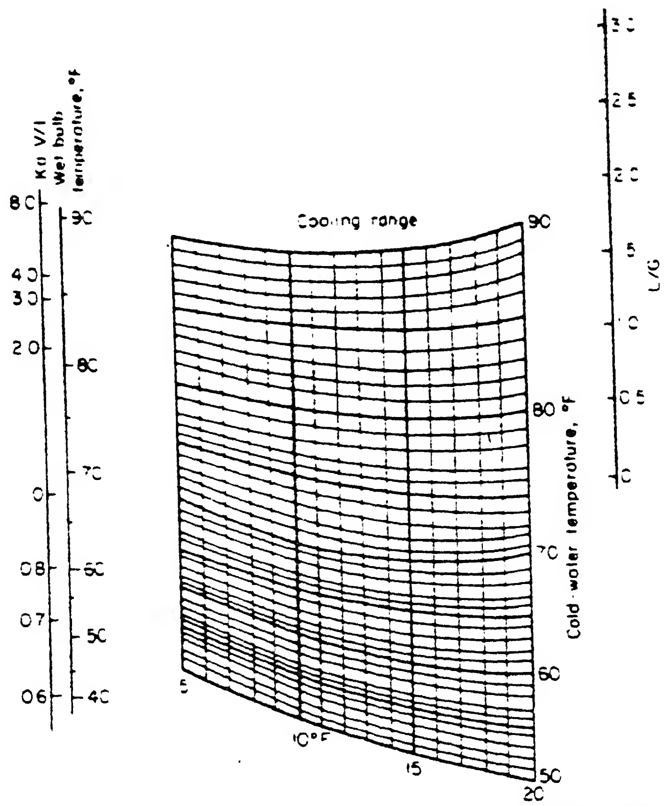
$$\text{Pump bhp} = \frac{\text{gal/min (ht)}}{3960 \times \text{pump efficiency}}$$

Where (ht) = total head, ft

d) Make Up Water Calculations

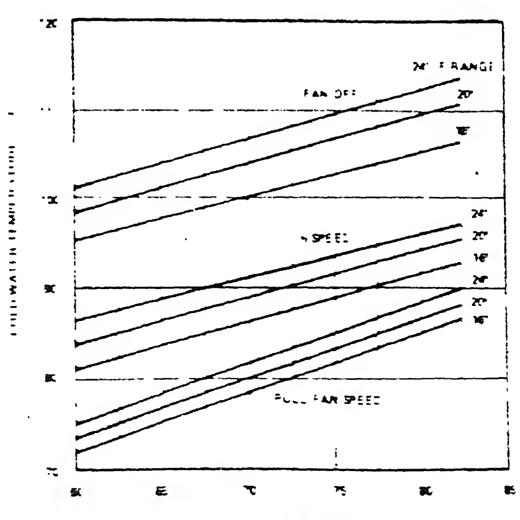
Wm	=	We + Wd + Wb
Where We	=	0.00085 Wc (T_1 -T_2)
Wd	=	0.01 × Wc
Wb	=	We/(C - 1)
Wm	=	Make up water - m^3/h. gal.min
Wd	=	Drift loss – – do –
We	=	Evaporation loss – do –
Wc	=	Circulation – water flow – gal.min
T_1, T_2	=	Inlet and Outlet water temp.°F
C	=	Value between three and five (generally 3)

EXHIBIT 5



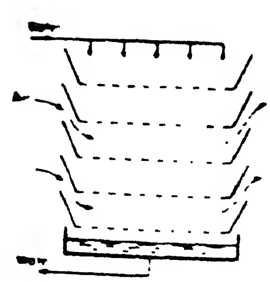
Nomograph of cooling-tower characteristics (Wood and Betts Engineer 189,4912, 337 1950)

EXHIBIT 7

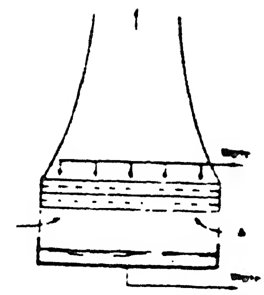


Typical plot of cooling-tower performance at varying fan speeds

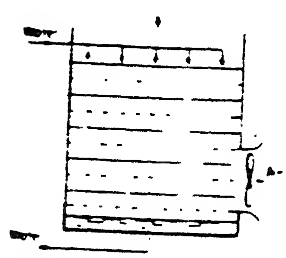
EXHIBIT 6



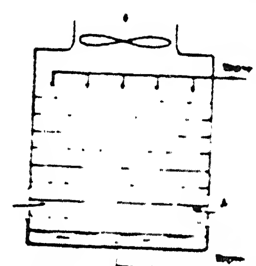
a)Atmospheric



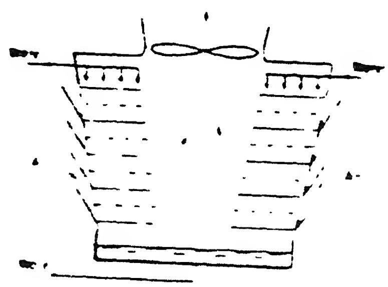
b)Natural draft



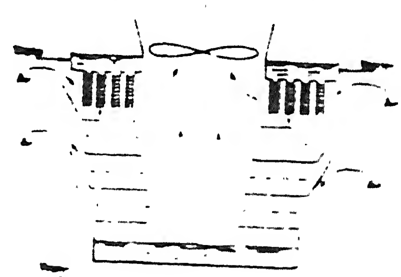
c)Forced draft



d)Counter current induced draft



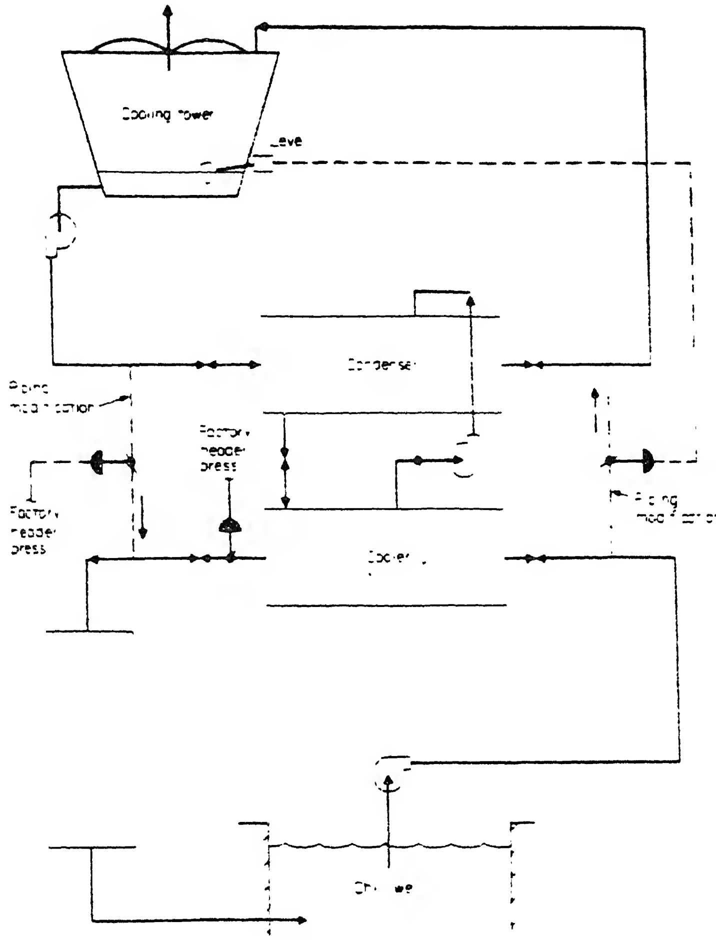
e)Cross flow induced draft



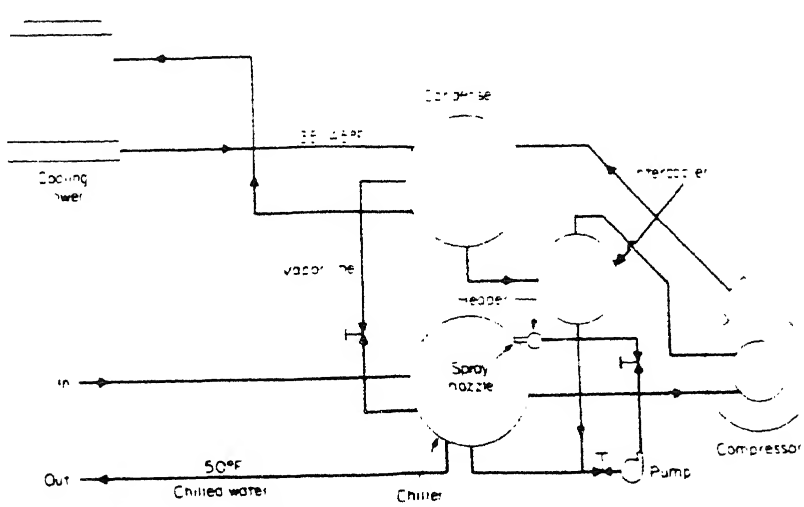
f)Wet Dry tower

COOLING TOWER ARRANGEMENTS

EXHIBIT 8



Cooling-tower water for direct cooling during winter months



Cooling-tower use on a thermocycle system during winter months

References

1. *Chemical Engineers Hand Book.* Robert H. Perry & C.H. Chilton.
2. *Process Heat Transfer.* Kern.
3. *Mass Transfer Operations.* Treybal.
4. *Introduction to Chemical Engg.* Badger & Banchero.
5. *Unit Operations of Chemical Engg.* McCabe & Smith.
6. *Mass Transfer Process Calculations.* Sawistowski & Smith